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# Dual-Task in Large Perceptual Space Reveals Subclinical Hemispatial Neglect

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**Abstract**

**Objective:** Both clinically observable and subclinical hemispatial neglect are related to functional disability. The aim of the present study was to examine whether increasing task complexity improves sensitivity in assessment and whether it enables the identification of subclinical neglect. **Method:** We developed and compared two computerized dual-tasks, a simpler and a more complex one, and presented them on a large, $173 \times 277$ cm screen. Participants in the study included 40 patients with unilateral stroke in either the left hemisphere (LH patient group, $n = 20$) or the right hemisphere (RH patient group, $n = 20$) and 20 healthy controls. In addition to the large-screen tasks, all participants underwent a comprehensive neuropsychological assessment. The Bells Test was used as a traditional paper-and-pencil cancellation test to assess neglect. **Results:** RH patients made significantly more left hemifield omission errors than controls in both large-screen tasks. LH patients' omissions did not differ significantly from those of the controls in either large-screen task. No significant group differences were observed in the Bells Test. All groups' reaction times were significantly slower in the more complex large-screen task compared to the simpler one. The more complex large-screen task also produced significantly slower reactions to stimuli in the left than in the right hemifield in all groups. **Conclusions:** The present results suggest that dual-tasks presented on a large screen sensitively reveal subclinical neglect in stroke. New, sensitive, and ecologically valid methods are needed to evaluate subclinical neglect.

**Keywords:** Stroke, Unilateral neglect, Divided attention, Computer-based, Neuropsychological assessment, Reaction times

## INTRODUCTION

Hemispatial neglect is a common symptom of right hemisphere stroke (Ringman, Saver, Woolson, Clarke, & Adams, 2004). Severe neglect becomes clinically observable, for example, in activities of daily living and in neuropsychological screening tests (Gillen, Tennen, & McKee, 2005; Katz, Hartman-Maeir, Ring, & Soroker, 1999). Subclinical neglect is more demanding to diagnose but can result in functional disability (Bonato, Priftis, Marenzi, Umiltá, & Zorzi, 2012; Jehkonen et al., 2000).

Traditional paper-and-pencil tests are not sensitive in revealing subclinical neglect (Bonato & Deouell, 2013). They have also been criticized for their poor ecological validity since stimuli are static and presented in a narrow visual space (Bonato & Deouell, 2013; Hasegawa, Hirono, & Yamadori, 2011; Nakatani, Notoya, Sunahara, Takahashi, & Inoue, 2013; Ulm et al., 2013). There have been various attempts to improve traditional tests' sensitivity. These include, for example, increasing the number or similarity of target and distractor stimuli (Aglioti, Smania, Barbieri, & Corbetta, 1997; Basagni et al., 2017; Kaplan et al., 1991; Rapcsak, Verfaellie, Fleet, & Heilman, 1989; Sarri, Greenwood, Kalra, & Driver, 2009), using time limits in visual searching (Priftis, Di Salvo, & Zara, 2019), or requiring counting backward while performing the task (Robertson & Frasca, 1992).

The increased complexity of the test environment enhances assessment sensitivity in revealing neglect (Blini et al., 2016; Bonato, 2012, 2015; Bonato, Priftis, Marenzi, Umiltá, & Zorzi, 2010; Hasegawa et al., 2011; Robertson & Manly, 2004). While a large portion of this evidence comes from observations in patients with right hemisphere strokes (Bartolomeo, 2000; Bonato, 2015; Bonato et al., 2012; Bonato, Priftis, Umiltá, & Zorzi, 2013; Deouell, Sacher, & Soroker, 2005; Eramudugolla, Boyce, Irvine, & Mattingley, 2010; Smania et al., 1998; van Kessel,

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van Nes, Geurts, Brouwer, & Fasotti, 2013), there are also studies showing similar deficits in left hemisphere patients (Blini et al., 2016; Bonato et al., 2010).

New computerized assessment methods requiring divided attention and reacting to dynamic stimuli offer benefits over traditional tests (Bonato et al., 2010; van Kessel, van Nes, Brouwer, Geurts, & Fasotti, 2010; van Kessel et al., 2013). Variations in task complexity hinder the use of compensatory strategies, and reaction time measurements enhance precision (Bonato & Deouell, 2013). Traditional tests do not reach similar sensitivity (Deouell et al., 2005; Kim et al., 2010; Tanaka, Sugihara, Nara, Ino, & Ifukube, 2005; Tsirlin, Dupierrix, Chokron, Coquillart, & Ohlmann, 2009; Ulm et al., 2013; van Kessel et al., 2010, 2013) even if factors increasing discernment are introduced (Bonato et al., 2012).

Various studies have compared new assessment methods with traditional tests (e.g. Deouell et al., 2005; Kim et al., 2010; Tanaka et al., 2005; Ulm et al., 2013; van Kessel et al., 2010), and computerized dual-tasks with single tasks (Andres et al., 2019; Blini et al., 2016; Bonato, 2015; Bonato et al., 2010, 2012; van Kessel et al. 2013). However, to our knowledge, there is only limited research comparing different computerized dual-tasks. Some of these studies have reported different versions of the dual-task as being sensitive (Blini et al., 2016; Bonato et al., 2010, 2012; Peers, Ludwig, Cusack, & Duncan, 2006). It has also been shown that low complexity in the primary central task does not reveal neglect in secondary peripheral visual processing, but high complexity does (Vuilleumier & Driver, 2007). None of these dual-task studies has utilized large screens.

The aim of the present study was to examine whether varying the complexity of the dual-task would improve the sensitivity of the assessment and enable the identification of subclinical neglect. More specifically, we investigated whether a computerized dual-task paradigm and the use of a large perceptual field would yield sufficient complexity in order to differentiate the findings obtained through a traditional paper-and-pencil cancellation test, or whether additional factors increasing task demands would be required. To answer the research problem, we developed and compared two computerized dual tasks: one simpler and the other more complex. The tasks were presented on a 173 cm × 277 cm screen to enhance ecological validity. The Bells Test was used as a traditional cancellation test to assess neglect. While neglect may occur in different sensory modalities, this study focuses solely on the visual form.

## METHOD

### Participants

A total of 58 potentially eligible consecutive stroke patients receiving rehabilitation at the Neurology Outpatient Clinic of Helsinki University Hospital were selected for recruitment. Recruitment and data collection were carried out between June 2016 and February 2019. The inclusion criteria were native Finnish speakers with first-ever CT (computed tomography) or MRI (magnetic resonance imaging)-verified stroke; no prior neurological diagnosis or bilateral stroke; no visual field defect according to clinical neurological or neuro-ophthalmological evaluation; no primary impairment in hearing or sight (other than myopia or hyperopia corrected with glasses); no substance abuse; no severe aphasia or other significant cognitive or similar symptom preventing participation; and no severe hemiparesis or other significant motor symptom or psychiatric disease, which would complicate the cooperation. Altogether, 18 patients were excluded because of prior or bilateral stroke, visual field defect, or severe neglect, preventing cooperation. The patients included in the study comprised 20 right hemisphere (RH patient group, 9 men, mean age 53 $SD \pm 8$ years) and 20 left hemisphere (LH patient group, 15 men, mean age 51 $SD \pm 9$ years) stroke patients. Fourteen of the RH patients and 10 of the LH patients received multiprofessional neurological outpatient rehabilitation, while the rest of the patients received only neuropsychological outpatient rehabilitation.

Control participants included 20 healthy volunteers (8 men, mean age 46 $SD \pm 15$ years) matched with the patient groups in age, gender, and education. The characteristics of the patients and controls are shown in Table 1.

The study protocol was approved by the Ethics Committee of Helsinki University Hospital. All participants gave written informed consent for participation. The data included in the study were obtained in compliance with the Helsinki Declaration.

### Procedure

#### *Comprehensive neuropsychological assessment*

The comprehensive neuropsychological assessment consisted of tests covering multiple cognitive domains. Visual attention was examined with the Bells Test to assess neglect (Gauthier, Dehaut, & Joanette, 1989). Executive functions and processing speed were examined with the Trail Making Test, parts A and B (Reitan, 1958), the Brixton Spatial Anticipation Test (Burgess & Shallice, 1997), design, phonetic and semantic fluency (Jones-Gotman & Milner, 1977; Miller, 1984), and a dual-task modification of the Bourdon–Wiersma Test, including counting numbers backwards and visual dot cancellation (Vilkki, Virtanen, Surma-aho, & Servo, 1996). Memory was examined with working memory distraction, word list learning, and delayed recall (Christensen, 1979), and with subtests of the Wechsler Memory Scale, third edition (WMS-III): Letter-Number Sequencing and Visual Memory Span (Wechsler, 1997, 2008). Depression was evaluated with the Depression Scale, which consists of 10 items with scores ranging from 0 to 30 (Salokangas, Poutanen, & Stengard, 1995).

#### *Large-screen tasks*

*Apparatus.* A new computer-based method, the Active Space, was developed based on near-field imaging technology

**Table 1.** Characteristics of the patients and controls

| Demographic and clinical data | LH patients | RH patients | Controls | Statistics | df | *p* Value | Effect size |
|---|---|---|---|---|---|---|---|
| Age, years[a] | 51 (9) | 53 (8) | 46 (15) | X2 = 2.375 | 2 | .305 | $\eta^2 = .007$ |
| Gender, male/female[b] | 15/5 | 9/11 | 8/12 | $\chi^2 = 5.759$ | 2 | .056 | $V = .310$ |
| Education, years[a] | 16 (4) | 15 (3) | 16 (3) | X2 = 0.390 | 2 | .823 | $\eta^2 = -.028$ |
| Depression scale score[a] | 5 (4) | 5 (4) | 3 (4) | X2 = 4.158 | 2 | .125 | $\eta^2 = .038$ |
| Lesion type, hemorrhage/ischemia/both[b] | 1/18/1 | 3/12/5 | | $\chi^2 = 4.867$ | 2 | .088 | $V = .349$ |
| Days post-onset of stroke prior to study[a] | 105 (42) | 106 (45) | | $U = 199.5$; Z = −.014 | 1 | .989 | $r = -.002$ |
| Neuropsychological out-patient rehabilitation sessions prior to study[a] | 3 (2) | 3 (2) | | $U = 186.5$; Z = −.369 | 1 | .712 | $r = -.058$ |

*Note.* LH = left hemisphere stroke; RH = right hemisphere stroke.
[a] Mean (*SD*), Mann–Whitney *U*- or Kruskal–Wallis Tests (*U*/X2).
[b] Frequency, Pearson Chi-Square Test ($\chi^2$).

**Table 2.** Main technical parameters of detection and crash tasks

| Technical parameter | Detection task | Crash task |
|---|---|---|
| Peripheral task paradigm | Spherical colored flashes in various display positions. Response with mouse button 4 | Spheres cross the display in various directions, randomly colliding in a flash. Response with mouse button 4 |
| Target | Red sphere (RGB = 190,0,0) | Two colliding spheres |
| Response window | 250–1000 ms after target onset | 250–1500 ms after target onset |
| Sphere diameter | 100 mm | Moving sphere 90 mm, flash 240 mm |
| Sphere colors | Red (190,0,0); green (0,255,0); blue (0,0,255); cyan (0,255,255); yellow (255,255,0) | Moving sphere gray (127,127,127), flash white (255,255,255) |
| Flash time | 100 ms | 100 ms |
| Screen background | Solid gray (127,127,127) | Gray noise |
| Target locations | 10 on left, 10 on right side of display , random height and ISI | 24 on left, 24 on right, random height and sequence |
| ISI | 1.5 ± 1.5 s, random | N/A |
| ITI | 6.3 ± 3.8 s, random | 6.6 ± 5 s, random |
| Central task paradigm | Varying numbers in the display center. Response with mouse button 4 | Varying numbers in the display center. Response with voice burst to lavalier microphone |
| Numbers displayed | 0, 1, 2, and 3 in random order | 1, 2, 3, 4, 5, 6, 7, 8, and 9 in random sequence |
| Target | Number 2 | A number twice the preceding number |
| Response window | within 1000 ms after target onset | Within 1500 ms after target onset |
| Number height | 50 mm | 245 mm |
| Display time | 800 ms | 800 ms |
| ISI | 1 s | 1.5 s |
| ITI | 6,5 ± 4,5 s, random | 10 ± 5 s, random |

*Note.* RGB = red, green, blue color space; ISI = interstimulus interval; ITI = intertarget interval.

(Linnavuo, Kovalev, & Sepponen, 2010; Rimminen, Lindström, Linnavuo, & Sepponen, 2010). The Active Space includes several means of generating visual stimuli and measuring reaction times. The main visual stimuli generator is a short throw video projector (Epson EB-680, Seiko EPSON Corporation, Suwa, Japan) producing a display of height 173 cm and a width of 277 cm on the wall. The midpoint of the screen is located 120 cm from the floor. The pixel size of the display is 1.9 mm. Control of the Active Space and the task applications are implemented using LabVIEW™ systems engineering software (National Instruments, Austin, TX, USA).

In the research setting, the participant was seated in a chair facing the screen at a 180-cm distance. Thus, the display appeared at an angle of approximately 75° horizontally and 51° vertically. The participants performed two distinct dual-tasks. In both, a peripheral visual field task was presented simultaneously with a numeric central task. A short training, including verbal guidance, preceded the actual test session.

*Tasks.* The main technical parameters of the large-screen tasks are listed in Table 2.

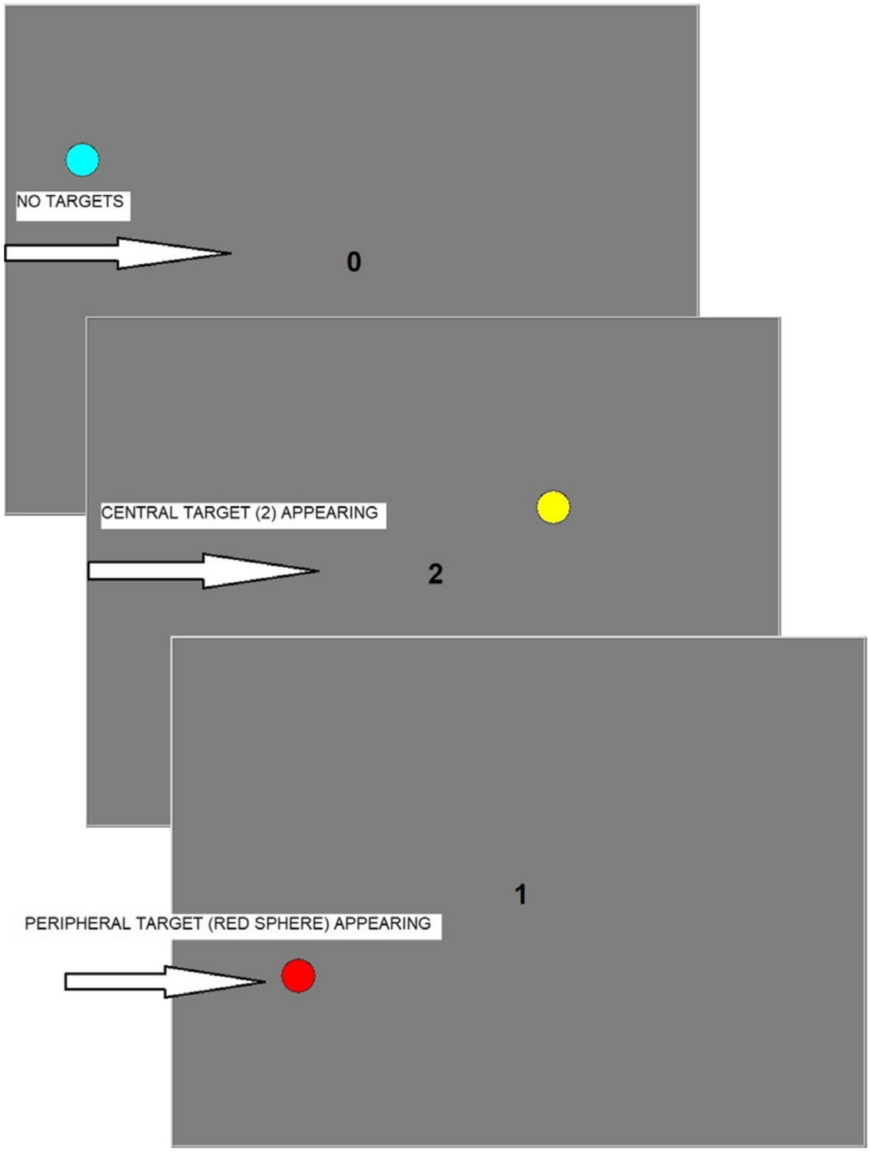


**Fig. 1.** Visualization of the Detection task. Initially, no targets are visible (top), then a central target appears (middle), and last, a red peripheral target sphere flashes in the left hemifield (bottom).

*Detection task.* In the peripheral visual field task, the participants were instructed to observe and react to a red sphere flashing among other colored ones, with all spheres appearing one at a time. For the central task, numbers appeared in the center of the screen. Participants were instructed to observe the continuously changing numbers and react only to the number 2. As part of the dual-task paradigm, subjects performed the peripheral visual field task and the central task simultaneously, but peripheral and central targets never appeared at the same time.

The duration of the Detection task was 2 min, and it was preceded by three trial runs of 30 s: first, both individual tasks were practiced separately, and finally, in the third trial run, the combined dual-task was practiced.

Correct reactions and reaction times, as well as missed stimuli, were extracted. A response was interpreted as "missed" if the participant failed to respond within the allowed temporal window of 1000 ms. If the participant responded before the target appeared or earlier than 250 ms after target onset, the reactions were excluded as anticipatory errors. Reactions deviating more than 2.5 *SD* from the mean were also excluded as outliers. This was done separately for each participant and condition. A total of 2% of all reactions were excluded. A visualization of the Detection task is presented in Figure 1.

*Crash task.* The peripheral visual field task was to observe and react to a collision of two moving gray spheres, resulting in a white flash appearing on the screen. In the central task, numbers appeared at the center of the display. The participants were instructed to follow the continuously changing numbers and react by saying the word "hep" into a lavalier microphone any time a number presented on the screen was exactly twice as high as the immediately preceding figure (alternatives: $1 \rightarrow 2, 2 \rightarrow 4, 3 \rightarrow 6, 4 \rightarrow 8$). As part of the dual-task paradigm, subjects performed the peripheral visual field

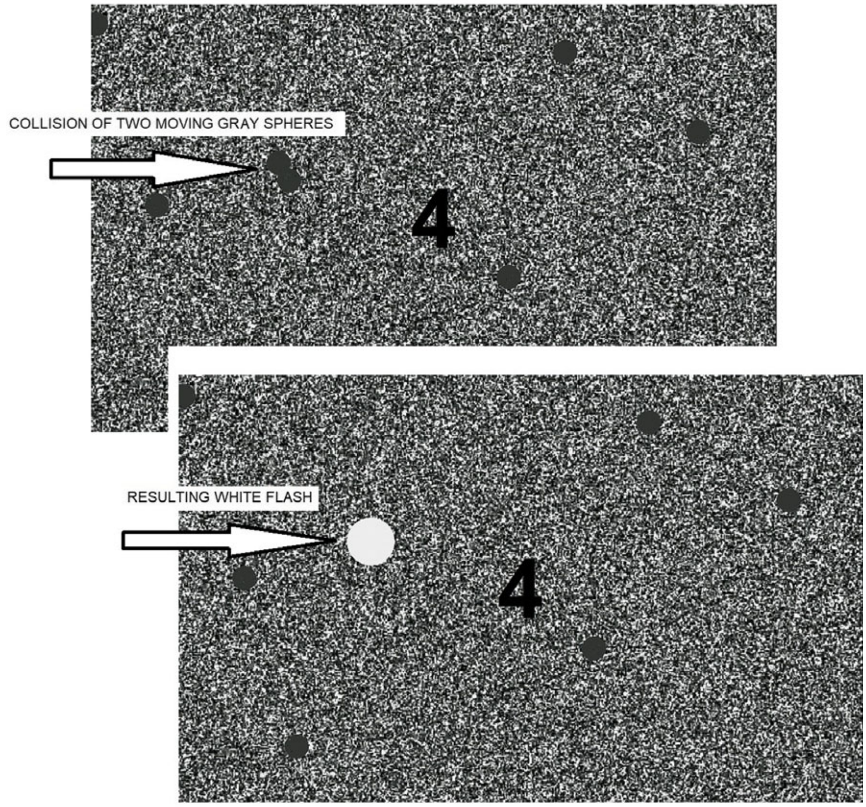


**Fig. 2.** Visualization of the Crash task. A collision is just happening (top), resulting in a white flash in the left hemifield (bottom).

task and the central task simultaneously, but peripheral and central targets never appeared at the same time.

The duration of the Crash task was 4 min and was preceded by three trial runs of 30 s: first, both individual tasks were practiced separately, and finally, in the third trial run, the combined dual-task was practiced.

Correct reactions and reaction times, as well as missed stimuli, were extracted. A response was interpreted as "missed" if the participant failed to respond within the allowed temporal window of 1500 ms. If the participant responded before the target appeared, or earlier than 250 ms after target onset, the reactions were excluded as anticipatory errors. Also, reactions deviating more than 2.5 *SD* from the mean were excluded as outliers. This was done separately for each participant and condition. A total of 3% of all reactions were excluded. The visualization of the Crash task is presented in Figure 2.

The Crash task was the more complex of the two dual-tasks. Compared to Detection, Crash introduced additional task demands through (1) increased arithmetic demands of the central task, (2) required different reactions in the central and peripheral tasks, (3) doubled the task duration, and (4) decreased the prominence of the targets from the background. All participants performed the Detection task first.

## Data Analysis

The Statistical Package for the Social Sciences (Version 25.0, IBM Corporation, Armonk, NY, USA) was used for statistical analyses. Large-screen task variables were created by calculating the average hit rates and reaction times separately for the left and right peripheral targets. Demographics, clinical and neuropsychological data, and the hit rates of the large-screen tasks were analyzed by using nonparametric methods due to the skewed distribution of the variables. Analyses were performed by using the Mann–Whitney *U*- or Kruskal–Wallis Tests (*U*/X2) for continuous variables and the Pearson's Chi-Square Test ($\chi^2$) for categorical variables. Dunn's Test was used for *post hoc* analyses. Within-group analyses (hit rate differences between the two hemifields) were performed using the Wilcoxon Signed-Rank Test. Reaction times were analyzed by using mixed analysis of variance (ANOVA) with *Group* (RH patients *vs*. LH patients *vs*. controls) as the between-participants factor and *Hemifield* (left *vs*. right) as well as *Task* (Crash task *vs*. Detection task) as within-participants factors. For multiple pairwise comparisons, the *p* values were adjusted using the Bonferroni correction in all *post hoc* analyses. Effect sizes were calculated by computing eta squared ($\eta^2$) for the Kruskal–Wallis Test, *r* for the Mann–Whitney *U*, Wilcoxon Signed-Rank, and Dunn's Tests, Cramer's *V* for Pearson's Chi-Square Test, and partial eta squared ($\eta^2_{\text{partial}}$) for mixed ANOVA (Tomczak & Tomczak, 2014). For significant group differences, Cohen's descriptions for $\eta^2_{\text{(partial)}}$ (large effect: .14, medium effect: .06, small effect: .01) and for *r* (large effect: .5, medium effect: .3, small effect: 1) were used (Cohen, 1988, pp. 79–80, 283–287, 366–368). The level of statistical significance was set at .05.

## RESULTS

### Patient and Control Characteristics

No significant differences were observed between the patient and control groups in demographic or clinical variables (Table 1).

### Comprehensive Neuropsychological Assessment

Statistical analyses of the comparisons between the patients and controls in neuropsychological test scores are shown in Table 3. RH patients were significantly slower than the controls in the Trail Making Test A. Both RH and LH patients performed significantly worse than controls in design fluency. Also, LH patients performed significantly worse than controls in phonetics and RH patients in semantic fluency. Finally, LH patients performed significantly worse than controls in the Bourdon–Wiersma dot cancellation single task and in the dot cancellation and number count dual-tasks. LH and RH patients did not differ significantly on any of the neuropsychological variables.

### Large-Screen Tasks

#### Hit rates

Hit rates for the large-screen tasks and statistical comparisons between the participant groups and the two hemifields are shown in Table 4. One right hemisphere stroke patient failed to perform Crash, and therefore, the related analyses are missing one patient (marked with • in Tables 4 and 5).

*Detection task.* The RH patients missed significantly more targets than the controls in the left hemifield but not in the right hemifield (see Figure 3). The LH patients did not differ significantly from the controls, and no significant differences in hit rates occurred between the patient groups. In the comparison of the two hemifields, the RH patients missed significantly more left hemifield than right hemifield targets (see Figure 3). No significant differences occurred between the two hemifields of the LH patients or the controls.

*Crash task.* The RH patients missed significantly more left hemifield targets than the controls, but no significant differences occurred in right hemifield targets (see Figure 3). The LH patients and the controls, or the patient groups, did not differ significantly in either hemifield. In the comparison of the two hemifields, the controls missed significantly more right than left hemifield targets (see Figure 3). No significant hemifield differences occurred in either patient group.

#### Reaction times

Average reaction times and statistical analyses of the between- and within-participants' effects are shown in Table 5.

There were no significant differences in reaction times for the Detection or Crash targets between RH or LH patients and controls, nor between the patient groups. However, in all groups, within-participants comparisons showed significant *task* and *hemifield* × *task* effects, with the reaction times for Crash being slower than those for Detection, and for Crash, they were slower over the left than the right hemifield (see Figure 4).

## DISCUSSION

We examined whether varying the complexity of tasks would improve the sensitivity of the assessment and enable the identification of subclinical neglect. We developed and compared two computerized tasks. In both tasks, we used a dual-task paradigm which is reportedly sensitive in detecting neglect (Bonato, 2012; Robertson & Frasca, 1992; van Kessel et al., 2013). We presented the tasks on a large screen in order to enhance ecological validity (Nakatani et al., 2013; Ulm et al., 2013). Of particular interest was finding whether the demands of the simpler dual-task (Detection) were sufficient to differentiate the findings obtained through the traditional Bells Test, or whether additional demands introduced in the more complex dual-task (Crash) would be required.

The main findings of our study are that both the simpler and more complex large-screen dual-tasks were sensitive in identifying RH patients' subclinical neglect. The RH group missed significantly more left Detection and Crash targets than the control group. The RH group also missed significantly more Detection targets in their left than in their right hemifields. RH patients' neglect did not become evident in the traditional Bells Test. LH patients' performance did not differ from the controls in either of the large-screen tasks or the Bells Test. Task complexity had a general rather than a specifically neglect-revealing effect on reaction times. All groups showed significantly slower reactions for Crash than Detection targets, and they showed prolonged Crash reactions in the left compared to the right hemifields. Both patient groups differed from the controls in several cognitive domains in the comprehensive neuropsychological assessment but did not differ from each other.

The finding that RH patients missed significantly more left targets than the controls in the large-screen tasks but not in the Bells Test was in line with various previous studies comparing new computerized visuospatial and traditional tests (Deouell et al., 2005; Kim et al., 2010; Tanaka et al., 2005; Ulm et al., 2013; van Kessel et al., 2010). Hence, an absence of symptoms in simpler test environments is not necessarily consistent with observations in more complex ones (Blini et al., 2016; Bonato, 2015; Bonato et al., 2010, 2012; Hasegawa et al., 2011). It is possible that the rehabilitation received by the patients may have affected our findings at least to a degree, as early-stage neuropsychological rehabilitation typically utilizes traditional pen-and-paper cancellation tasks. Therefore, the Bells Test may have fallen under a test type familiar to the patients, thereby facilitating the use of compensatory strategies for neglect. It should also be noted that large-screen tasks assess neglect in the

**Table 3.** Comprehensive neuropsychological assessment of the patients and controls

| Neuropsychological variables[a] | | LH patients | RH patients | Controls | Statistics (X2) | df | *p* Value | Effect size |
|---|---|---|---|---|---|---|---|---|
| Bells Test, omissions left | | 1 (1) | 1 (1) | 1 (1) | 3.011 | 2 | .222 | $\eta^2 = .018$ |
| Bells Test, omissions right | | 1 (1) | 1 (1) | 0 (1) | 4.973 | 2 | .083 | $\eta^2 = .052$ |
| Trail Making Test A, s | | 42 (20) | 49 (23) | 29 (9) | 10.960 | 2 | **.004** | $\eta^2 = .157$ |
| *Post hoc* comparisons | Mean ranks | 32.23 | 38.65 | 20.62 | | | | |
| Controls *versus* RH patients | | | | | 18.025 | | **.003** | $r = .52$ |
| LH patients *versus* RH patients | | | | | 6.425 | | .733 | |
| Controls *versus* LH patients | | | | | 11.600 | | .107 | |
| Trail Making Test B, s | | 103 (62) | 94 (36) | 71 (26) | 5.252 | 2 | .072 | $\eta^2 = .057$ |
| Brixton Spatial Anticipation Test, error score | | 14 (6) | 16 (6) | 12 (4) | 4.884 | 2 | .087 | $\eta^2 = .051$ |
| Phonetic fluency, amount | | 14 (6) | 17 (4) | 21 (7) | 8.317 | 2 | **.016** | $\eta^2 = .111$ |
| *Post hoc* comparisons | Mean ranks | 22.75 | 30.12 | 38.62 | | | | |
| LH patients *versus* controls | | | | | −15.875 | | **.012** | $r = -.46$ |
| LH patients *versus* RH patients | | | | | 7.375 | | .542 | |
| RH patients *versus* controls | | | | | −8.500 | | .369 | |
| Semantic fluency, amount | | 21 (8) | 21 (5) | 26 (6) | 9.300 | 2 | **.010** | $\eta^2 = .128$ |
| *Post hoc* comparisons | mean ranks | 27.07 | 24.35 | 40.08 | | | | |
| RH patients *versus* controls | | | | | −15.725 | | **.013** | $r = -.45$ |
| RH patients *versus* LH patients | | | | | −2.725 | | 1.000 | |
| LH patients *versus* controls | | | | | −13.000 | | .055 | |
| Design fluency, amount | | 8 (3) | 8 (3) | 11 (4) | 13.952 | 2 | **.001** | $\eta^2 = .210$ |
| *Post hoc* comparisons | Mean ranks | 23.68 | 25.52 | 42.30 | | | | |
| LH patients *versus* controls | | | | | −18.625 | | **.002** | $r = -.54$ |
| RH patients *versus* controls | | | | | −16.775 | | **.007** | $r = -.48$ |
| LH patients *versus* RH patients | | | | | 1.850 | | 1.000 | |
| Bourdon–Wiersma number count (single task), amount | | 43 (12) | 42 (14) | 49 (15) | 1.991 | 2 | .370 | $\eta^2 = .000$ |
| Bourdon–Wiersma dot cancellation (single task), amount | | 28 (8) | 28 (8) | 34 (7) | 7.638 | 2 | **.022** | $\eta^2 = .099$ |
| *Post hoc* comparisons | Mean ranks | 25.88 | 26.32 | 39.30 | | | | |
| LH patients *versus* controls | | | | | −13.425 | | **.045** | $r = -.38$ |
| LH patients *versus* RH patients | | | | | .450 | | 1.000 | |
| RH patients *versus* controls | | | | | −12.975 | | .056 | |
| Bourdon–Wiersma number count (dual-task), amount | | 23 (8) | 25 (9) | 31 (11) | 6.672 | 2 | **.036** | $\eta^2 = .082$ |
| *Post hoc* comparisons | mean ranks | 23.85 | 29.62 | 38.02 | | | | |
| LH patients *versus* controls | | | | | −14.175 | | **.031** | $r = -.41$ |
| LH patients *versus* RH patients | | | | | 5.775 | | .886 | |
| LH patients *versus* controls | | | | | −8.400 | | .384 | |
| Bourdon–Wiersma dot cancellation (dual-task), amount | | 18 (7) | 20 (6) | 25 (7) | 9.424 | 2 | **.009** | $\eta^2 = .130$ |
| *Post hoc* comparisons | mean ranks | 23.02 | 28.77 | 39.70 | | | | |
| LH patients *versus* controls | | | | | −16.675 | | **.008** | $r = -.38$ |
| LH patients *versus* RH patients | | | | | 5.750 | | .892 | |
| RH patients *versus* controls | | | | | −10.925 | | .143 | |
| Letter-Number Sequencing, score | | 9 (3) | 9 (3) | 11 (2) | 6.434 | 2 | **.040** | $\eta^2 = .078$ |
| *Post hoc* comparisons | mean ranks | 27.45 | 25.60 | 38.45 | | | | |
| RH patients *versus* controls | | | | | −12.850 | | .057 | |
| RH patients *versus* LH patients | | | | | −1.850 | | 1.000 | |
| LH patients *versus* controls | | | | | −11.000 | | .134 | |
| Visual Memory Span, score | | 15 (4) | 14 (3) | 16 (4) | 4.084 | 2 | .130 | $\eta^2 = .037$ |
| Verbal working memory distraction, score | | 14 (4) | 14 (3) | 16 (2) | 5.046 | 2 | .080 | $\eta^2 = .053$ |
| List learning, sum | | 28 (6) | 32 (6) | 32 (5) | 5.082 | 2 | .079 | $\eta^2 = .054$ |
| Delayed recall, amount | | 7 (2) | 7 (3) | 8 (2) | 4.346 | 2 | .114 | $\eta^2 = .041$ |

*Note.* LH = left hemisphere stroke; RH = right hemisphere stroke.
[a] Mean (*SD*), Kruskal–Wallis Test (X2), mean ranks and *post hoc* comparisons presented for significant group differences.

**Table 4.** Hit rates for the large-screen tasks in the LH and RH patients and controls

| Average hit rates (%) and related group-comparisons[a] | | LH patients | RH patients | Controls | Statistics (X2) | df | *p* value | Effect size |
|---|---|---|---|---|---|---|---|---|
| Crash task, left hemifield | | 85% | •71% | 93% | 8.404 | 2 | **.015** | $\eta^2 = .114$ |
| *Post hoc* comparisons | mean ranks | 29.27 | 22.32 | 38.02 | | | | |
| Controls *versus* RH patients | | | | | −15.709 | | **.012** | $r = -.46$ |
| LH patients *versus* RH patients | | | | | 6.959 | | .602 | |
| Controls *versus* LH patients | | | | | −8.750 | | .309 | |
| Crash task, right hemifield | | 80% | •81% | 88% | 3.289 | 2 | .193 | $\eta^2 = .023$ |
| Detection task, left hemifield | | 92% | 85% | 97% | 6.473 | 2 | **.039** | $\eta^2 = .078$ |
| *Post hoc* comparisons | Mean ranks | 30.60 | 24.10 | 36.80 | | | | |
| Controls *versus* RH patients | | | | | −12.700 | | **.033** | $r = -.40$ |
| LH patients *versus* RH patients | | | | | 6.500 | | .579 | |
| Controls *versus* LH patients | | | | | −6.200 | | .643 | |
| Detection task, right hemifield | | 93% | 96% | 98% | 2.355 | 2 | .308 | $\eta^2 = .000$ |
| Hit rate -comparisons between the two hemifields[b] | | | | | Statistics (*Z*) | | *p* value | Effect size (*r*) |
| Crash task | | | | | | | | |
| LH patients | | | | | −1.738 | | .082 | −.39 |
| RH patients | | | | | −1.386 | | .166 | −.32 |
| Controls | | | | | −2.278 | | **.023** | −.51 |
| Detection task | | | | | | | | |
| LH patients | | | | | −.472 | | .637 | −.11 |
| RH patients | | | | | −2.234 | | **.025** | −.50 |
| Controls | | | | | −.447 | | .655 | −.10 |

*Note.* Data for 1 patient missing. LH = left hemisphere stroke; RH = right hemisphere stroke.
[a] Kruskall–Wallis Test (X2), mean ranks and *post hoc* comparisons presented for significant group differences.
[b] Wilcoxon Signed-Rank Test (Z).

**Table 5.** Reaction times for the large-screen tasks in the LH and RH patients and controls

| Average reaction times, ms (and standard deviations)[a] | LH patients | RH patients | Controls | Statistics (Wilks λ; *F*) | df | *p* value | Effect size ($\eta^2_{\text{partial}}$) |
|---|---|---|---|---|---|---|---|
| Crash task | | | | | | | |
| left hemifield | 721 (106) | •739 (89) | 670 (89) | | | | |
| right hemifield | 704 (84) | •708 (101) | 657 (93) | | | | |
| Detection task | | | | | | | |
| left hemifield | 508 (60) | 534 (77) | 489 (55) | | | | |
| right hemifield | 525 (62) | 533 (87) | 491 (52) | | | | |
| Between groups -comparisons: | | | | 3.049 | 2 | .055 | .098 |
| Within-participants' -comparisons: | | | | | | | |
| Hemifield | | | | .960; 2.333 | 1 | .132 | .040 |
| Hemifield × Group | | | | .966; 0.986 | 2 | .379 | .034 |
| Task | | | | .141; 342.371 | 1 | **<.001** | .859 |
| Task × Group | | | | .982; 0.501 | 2 | .609 | .018 |
| Hemifield × Task | | | | .899; 6.272 | 1 | **.015** | .101 |
| Hemifield × Task × Group | | | | .991; 0.246 | 2 | .783 | .009 |

*Note.* Data for 1 patient missing. LH = left hemisphere stroke; RH = right hemisphere stroke.
[a] Repeated-measures-ANOVA.

extrapersonal space while the Bells Test does so in the peripersonal space. Some studies (e.g. Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991) have indicated that these forms of neglect can occur separately from each other. It is, therefore, possible that RH patients in this study suffered from extrapersonal but not peripersonal neglect. However, most previous studies (e.g. Andres et al., 2019; Blini et al., 2016; Bonato, 2015; Bonato et al., 2010, 2012), which have compared more complex computer-based tasks to pen-and-paper methods in the peripersonal space, have found that the computer-based tasks are more sensitive in identifying mild neglect.

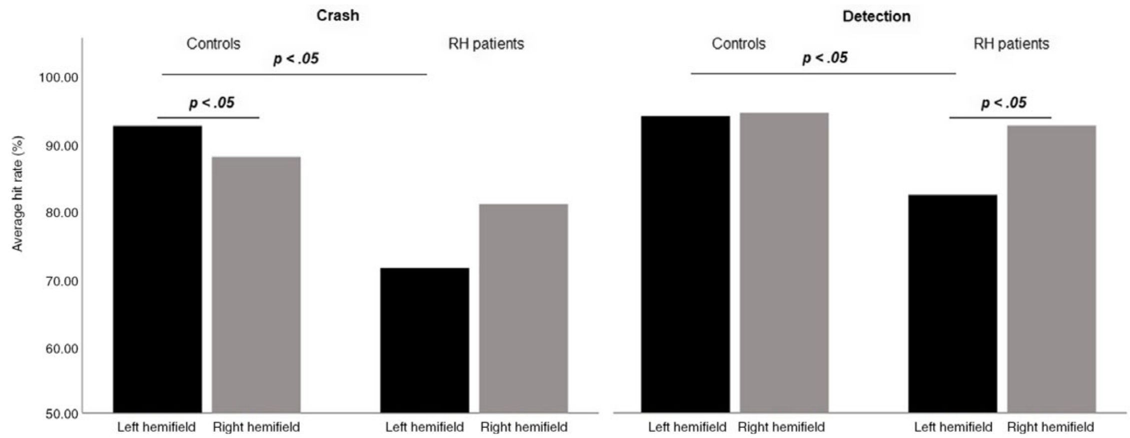


**Fig. 3.** Average hit rates of the controls and the RH patients in Crash and Detection tasks. In both tasks, RH patients missed significantly more left hemifield targets than controls. Also, RH patients missed significantly more left than right hemifield targets in Detection, and controls missed significantly more right than left hemifield targets in Crash.

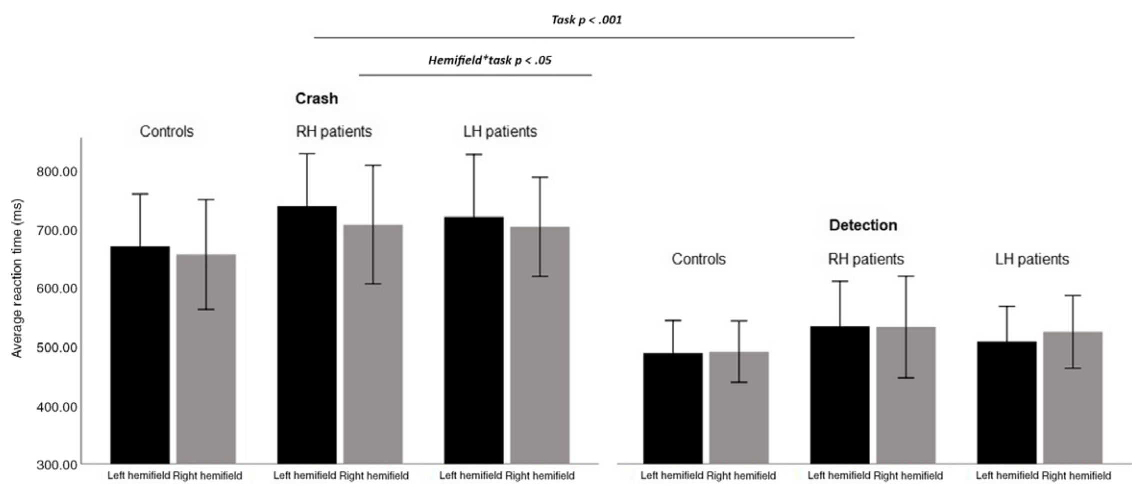


**Fig. 4.** Average reaction times of the participant groups in Crash and Detection tasks (error bars represent ±1 *SD*). In all groups, the reaction times for Crash were significantly slower than those for Detection, and for Crash, they were slower over the left than the right hemifield.

Which factors contributed to both large-screen tasks being sensitive in identifying RH patients' subclinical neglect? Traditional tests have been criticized for their poor ecological validity since the stimuli are presented in a narrow visual space (Nakatani et al., 2013; Ulm et al., 2013). Hence, a large test field may be one of the components that increase sensitivity. Further, a dual-task assignment presumably eliminates the typical top-down coping mechanism and brings out symptoms that would otherwise be compensated for (Andres et al., 2019; Bonato, 2015; Robertson & Frasca, 1992; Robertson & Manley, 2004; van Kessel et al., 2013). Increases in task demands need not be either visuospatial or attentional in order to improve assessment (Mennemeier, Morris, & Heilman, 2004; Ricci et al., 2016). For example, arithmetic processing, which was needed in our large-screen central tasks, also enhances task demands to better bring out neglect (Mennemeier et al., 2004; Robertson & Frasca, 1992). Presumably, simultaneous arithmetic and visuospatial processing introduces deficits in both general and lateralized attention (Ricci et al., 2016). These components interact in neglect, whereby the presence of a general deficit exacerbates the severity of a lateralized one (van Kessel et al., 2010). Successful performance in the large-screen tasks also requires effective executive functions, processing speed, and working memory. These cognitive domains are the ones typically affected after stroke (Farnè et al., 2004; Jaillard, Naegele, Trabucco-Miguel, LeBas, & Hommel, 2009; Jokinen et al., 2015; Middleton et al., 2014; Nys et al., 2005). Based on the comprehensive neuropsychological assessment, this was also the case with our patients. It may be that these other cognitive deficits exhausted RH patients' attentional resources while performing the large-screen tasks and weakened their ability to compensate for neglect (Smit, Eling, & Coenen, 2004a; van Kessel et al., 2010). Apparently, sufficient load (i.e. increased task difficulty together with limited processing time) is needed to improve assessment (Priftis et al., 2019).

Although the large-screen tasks differentiated the RH patients from the controls in terms of left hemifield omissions, there were no group differences in reaction times. This finding seems logical considering the fact that the tasks required constant reactions on short interstimulus intervals, and responses were only registered during a short window. Therefore, it may be that longer response times would register more readily as omitted. Supporting the above, some previous studies (Deouell et al., 2005; Rengachary, d'Avossa, Sapir, Shulman, & Corbetta, 2009) that successfully demonstrate right hemisphere patients' neglect in reaction times have either deliberately chosen a long response window or substituted missed trials with the longest-permitted reaction time. This was done to maximize hits and, hence, improve the signal-to-noise ratio of reaction times. Another essential factor behind the finding might be the fact that controls displayed prolonged Crash reactions for the left as well. This possibly hindered the group difference from becoming noticeable.

In the Crash task, the reactions to the left-side targets were significantly slower than those to the right-side targets. Subject groups did not differ in this respect. As the simpler dual-task, Detection, failed to identify this difference, the increased task complexity possibly influenced the results. This interpretation is supported by the observation of considerably shorter reaction times in Detection than Crash. More demanding tasks could be expected to require more time to process (Bartolomeo, 2000). Crash was not only more demanding from a cognitive perspective, but its duration was also twice that of Detection, and all participants performed Detection first. It may be that the increases in both difficulty and duration, as well as the presentation order, affected the results, possibly through alertness. In fact, several studies have suggested that a decrease in alertness—be it from sleep deprivation, a long test protocol, or high task demands—is associated with a rightward orientation shift. In addition to patients with right hemisphere strokes (Peers et al., 2006; Robertson et al., 1997), similar behaviors have been found with left hemisphere patients (Peers et al., 2006) as well as healthy subjects (Bellgrove, Dockree, Aimola, & Robertson, 2004; Dobler et al., 2005; Dodds et al., 2008; Fimm, Willmes, & Spijkers, 2006; Pérez et al., 2009; Takio, Koivisto, Laukka, & Hämäläinen, 2011; Takio, Koivisto, Tuominen, Laukka, & Hämäläinen, 2013). This phenomenon has been explained by the domination of right hemispheres in both spatial and sustained attention, as well as their close interconnection (Cavézian et al., 2015; Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; He et al., 2007; Posner & Petersen, 1990; Robertson, 1989, 1993, 2001). It may be that, as proposed by Bellgrove and coworkers (2004), the reduction in sustained attention is associated with decreased activity within the frontoparietal attentional networks underlying both sustained and spatial attention. This decreased activity, then, weakens the right hemisphere spatial attentional systems and drives attention toward the right (Bellgrove et al., 2004). Thus, in the present study, the general rightward bias in Crash reactions might be related to a possible alertness decrement effect as a result of depleted resources in high-complexity tasks (Peers et al., 2006; Smit et al., 2004a; Smit, Eling, & Coenen, 2004b; Takio, Koivisto, & Hämäläinen, 2014).

Generalizations from the present interpretations should be made with some caution. The sample size of the study sets certain limitations. Our findings were also inconsistent with some previous studies. There are observations of high task complexity emphasizing right-sided neglect in left hemisphere patients (Blini et al., 2016; Bonato et al., 2010). In our study, conversely, high complexity caused a rightward shift. A possible explanation for this contradiction might be that the LH patients in the present study did not suffer from even subclinical neglect. Hence, the high task complexity would have caused a similar reaction time effect in LH patients as displayed by healthy controls. Another reason may be that the rightward bias in our study was observed in terms of reaction times, while the abovementioned studies analyzed hit rates. This might explain the contradiction which seems to be supported by healthy controls in our study displaying shorter but more inaccurate reactions toward the right. Supplementary studies are required to clarify this issue. Future studies may also uncover additional information on the effects of task duration on identifying neglect. A longer task would be a more ecologically valid way to assess whether neglect becomes more pronounced through the effects of load and fatigue. Such information would be crucial in a clinical setting, particularly with a view toward a patient's ability to work or operate a vehicle. Future studies should assess the effect of individual factors (i.e. the large perceptual field or the dual-task paradigm) in increasing the overall sensitivity of the method. The present study attempted to increase sensitivity by combining several factors known to increase sensitivity, and because of this, the significance of the individual factors remains elusive. Several previous studies (e.g. Andres et al., 2019; Blini et al., 2016; Bonato, 2015; Bonato et al., 2010, 2012; van Kessel et al. 2013) have already noted that a dual-task paradigm is in itself more sensitive than a single task in bringing out mild neglect. Therefore, the effect of the large visual field would require particular attention in future studies.

To conclude, in this study, we presented a new method for the assessment of visual neglect. We demonstrated that, in a large extrapersonal space, dual-tasks sensitively reveal right hemisphere stroke patients' subclinical neglect. It is important to identify and diagnose all forms of neglect in order to assess the efficacy of rehabilitation and to address specific concerns such as driving ability or working ability in tasks requiring high attention. More sensitive methods than traditional cancellation tests are needed to evaluate these issues. A large test field, together with dynamic stimuli, enhances ecological validity and sensitivity in neglect assessment.

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## CONFLICT OF INTEREST

The authors have no conflicts of interest to disclose.

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